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A COMPILATION OF AIR POLLUTANT EMISSION FACTORS FOR COMBUSTION PROCESSES, GASOLINE EVAPORATION, AND SELECTED INDUSTRIAL PROCESSES

Martin Mayer

Public Health Service
Cincinnati, Ohio

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Technical Assistance Branch
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CONTENTS

	Page
INTRODUCTION	1
SOURCE EMISSION FACTORS	
Aircraft Emissions	2
Asphalt Batching Plants	2
Automotive and Diesel Exhaust Emissions	4
Cement Production	4
Coffee Processing	7
Combustion	7
Coal	7
Natural Gas	11
Oil	11
Concrete Batching Plants	11
Ferrous and Non-Ferrous Foundries	14
Gasoline Evaporation	16
Iron and Steel Mills	18
Kraft Pulp Mills	21
Mineral Acid Manufacture	25
Nitric Acid	25
Phosphoric Acid	25
Sulfuric Acid	26
Petroleum Refineries	27
Solvent Evaporation from Dry Cleaning Plants	28
Refuse Disposal and Open Burning	31
Incineration of Waste	31
Open Burning	33
Uncontrolled Automobile Body Burning	33
APPENDIX	
Sources of Information Useful in Calculating Total Emissions	37
Combustion: Coal, Oil, and Natural Gas	37
Refuse Disposal	39
Automotive and Diesel Emissions	39
Gasoline Evaporation	42
Industrial Sources	42
A Method for Calculating Domestic Fuel Use from U.S. Bureau of Census Data	43
REFERENCES	47

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INTRODUCTION

The source emission factors presented in this report were compiled primarily for use in conducting an air pollutant emission inventory. The compilation is the result of an extensive literature survey and includes emission factors for the principal combustion and industrial processes. Obviously, the best emission factor to use for any specific source of air pollution is that resulting from source tests of the specific source. Unfortunately, many urban areas are not equipped to conduct the numerous and expensive stack testing studies needed for an emission inventory. The purpose of this compilation of emission factors is to provide the best available substitute to air pollution control agencies unable to conduct extensive source test programs.

In certain cases, particularly in the combustion and refuse disposal areas, a single number is presented for the emission factor for a specific pollutant. It should be understood that the number is usually a weighted average of several different values found in the listed references. The compilation of source emission factors presented is, in our judgment, the most accurate currently available. As new technical advances are made, however, and additional emission data become available in the literature, the present compilation should be revised to reflect the newer data and developments.

SOURCE EMISSION FACTORS

AIRCRAFT EMISSIONS

Johnson and Flynn have presented emission factors, in the form of pounds of pollutants emitted per thousand gallons of fuel consumed, for jet and piston aircraft.[1] Revised emission factors for turboprop aircraft were also obtained.[2] These factors, shown in Table 1, are combined and averaged figures for emissions during all phases of aircraft operation (taxi, takeoff, climbout, approach, and landing) that take place below the arbitrarily chosen altitude of 3500 feet. It was felt that emissions taking place at cruise altitude (above 3500 feet) were not of concern to air pollution authorities.

Data were obtained for fuel consumption in the three classes of aircraft,[2] so that the emission factors given in Table 2 could be expressed in pounds of pollutant emitted per flight. A flight is defined as the combination of a landing and a takeoff.

ASPHALT BATCHING PLANTS

An asphaltic concrete batching plant generally consists of a rotary dryer, screening and classifying equipment, an aggregate weighing system, a mixer, storage bins, and conveying equipment. Sand and aggregate are charged from bins into a rotary dryer. The dried aggregate at the lower end of the dryer is mechanically conveyed by a bucket elevator to the screening equipment where it is classified and dumped into storage bins. Weighed quantities of the sized products are

Table 1. EMISSION FACTORS FOR AIRCRAFT BELOW 3500 FEET
(lb/1000 gal of fuel consumed)

Type of emission	Jet aircraft[a]	Turbo-prop aircraft	Piston engine aircraft
Aldehydes	6	5	5
Carbon monoxide	56	40	2,450
Hydrocarbons	15	5	491
Oxides of nitrogen	37	23	147
Particulates	54	12	12

[a]No water injection on takeoff.

Table 2. EMISSION FACTORS FOR AIRCRAFT BELOW 3500 FEET
(lb/flight)[a]

Type of emission	Jet aircraft[b]	Turbo-prop aircraft		Piston engine aircraft	
	4 engines	2 engines	4 engines	2 engines	4 engines
Aldehydes	4	0.3	1.1	0.2	0.5
Carbon monoxide	35	2	9	74	245
Hydrocarbons	10	0.3	1.2	15	49
Oxides of nitrogen	23	1.1	5	4.4	15
Particulates	34	0.6	2.5	0.4	1.2

[a]A flight is the combination of a landing and a takeoff.

[b]No water injection on takeoff.

then dropped into the mixer along with asphalt, where the batch is mixed and dumped into trucks for transportation to the paving site. The combustion gases and fine dust from the rotary drier are exhausted through a precleaner. This is usually a single cyclone, but twin or multiple cyclones and other devices are also used. The precleaner catch is then discharged back into the bucket elevator where it continues in the process with the main bulk of the dried aggregate. The exit gas stream of the precleaner is usually passed through air pollution control equipment, normally scrubbers of the multiple centrifugal or baffled spray tower type.[3]

Dust and particulate emissions from the scrubbers usually average around 0.2 pound per ton of product produced. If no scrubbers are used, the dust and particulate emission averages around 5 pounds per ton of product produced.[3]

AUTOMOTIVE AND DIESEL EXHAUST EMISSIONS

The composition of automotive and diesel exhausts is characterized by greater amounts of carbon monoxide and hydrocarbons than that of emissions from other fuel burning processes. Automotive and diesel exhaust emissions, in pounds per 1,000 gallons of fuel consumed, are given in Table 3. Another way of presenting automobile emission factors, in pounds per vehicle mile, is explained in the appendix.

CEMENT PRODUCTION

Raw materials for the manufacture of cement are ground, mixed, and blended by either a wet or a dry process. In the dry process, the

Table 3. EMISSION FACTORS (lb/1000 gal)

Pollutant	Gasoline engines[a]	Diesel engines[b]
Aldehydes	4	10
Benzo(a)pyrene	0.3 gram/1000 gal[c]	0.4 gram/1000 gal[d]
Carbon monoxide	2910	60[a]
Hydrocarbons	524[e]	180
Oxides of nitrogen	113	222[f]
Oxides of sulfur	9	40
Ammonia	2[f]	n.a.[g]
Organic acids	4[f]	31[f]
Particulates	11	110

[a]Includes blowby emissions, but not evaporation losses (Reference 4).

[b]Reference 5.

[c]Reference 6.

[d]Reference 7.

[e]Includes 128 lb/1000 gal blowby emissions (Reference 8).

[f]Reference 9.

[g]Not available.

moisture content of the raw materials does not exceed 1 percent; in the wet process, a slurry of carefully controlled composition is made, generally having a moisture content ranging from 30 to 50 percent. After the raw materials are crushed and ground, they are introduced into a rotary kiln that is fired with pulverized coal, oil, or gas to produce a temperature of about 2700° F. Drying, decarbonating, and calcining are accomplished as the material passes through the kiln, resulting in the formation of a cement clinker. The clinker is cooled, mixed, ground with gypsum, and bagged for shipment as cement. Dust and fume in the waste gases of the kiln are the major sources of air pollution. Gaseous pollutants, notably sulfur dioxide, are also emitted from the kiln.[10]

Kiln emissions for the wet process of producing cement range from 15 to 50 pounds of dust per barrel of cement produced, with 28 pounds of dust per barrel of cement produced being a typical value. In the dry process, the losses range from 22 to 87 pounds of dust per barrel of cement produced, with 45 pounds of dust per barrel of cement being a typical value. Control of kiln dust emissions varies considerably depending upon the type and age of the control system. Typical collection efficiencies are: 80 percent for multicyclones; 90 percent for old electrostatic precipitators; 95 percent for multicyclones plus old electrostatic precipitator systems; 99+ percent for multicyclones plus new electrostatic precipitator systems; 99.5+ percent for fabric filter units either alone or in combination with multicyclones.[11]

COFFEE PROCESSING

Because coffee is imported in the form of green beans, it must be cleaned, blended, roasted, and packaged before it can be sold. The essential ingredients of the roasted beans may be extracted, spray dried, and marketed as instant coffee. In the roasting of coffee, chemical changes, such as the degradation of sugars, occur that bring out the characteristic flavor and aroma of the coffee.

In the indirect-fired roaster, a portion of the roaster gases are recirculated through the combustion area for destruction of smoke and odors by oxidation in the flame. In the direct-fired roaster, all the roaster gases are vented without recirculation through the flame. Essentially complete removal of both smoke and odors can be realized with a properly designed afterburner.

In the cleaner, contaminating materials lighter than the green beans are separated from the beans by an air stream. In the stoner, contaminating materials heavier than the roasted beans are separated from the beans, also by an air stream.

In the cooler, the hot roasted beans are quenched with water, thus emitting large quantities of steam and some particulate matter.[12] Table 4 summarizes the emissions from the various operations involved in coffee processing.

COMBUSTION

A. Coal

The burning of coal produces several different kinds of gaseous pollutants, including carbon monoxide, nitrogen oxides, sulfur oxides,

Table 4. PARTICULATE EMISSIONS FROM COFFEE ROASTING AND AUXILIARY OPERATIONS

Operation	Particulate emissions, without cyclone[a]		Particulate emissions, with cyclone[b]	
	grains/scf	lb/1000 lb green beans	grains/scf	lb/1000 lb green beans
Indirect fired roaster[c]	0.3 -0.6	0.8-4.0	0.09-0.127-0.15[d]	0.2-0.58-1.0
Direct fired roaster[c]	0.6 -0.9	3.0-5.0	0.17-0.193-0.22	0.9-1.12-1.3
Stoner, cooler cleaner, and handling systems combined	0.01-0.15	0.5-0.8	0.01-0.017-0.03	0.1-0.16-0.3

[a]Reference 13.

[b]Reference 12.

[c]Without afterburners.

[d]When 3 values are given, such as 0.09-0.127-0.15, the center value is the approximate average and the values at either end are the lowest and highest values reported.

aldehydes, and hydrocarbons. The quantities of these pollutants are dependent on the composition of the coal, the method of firing, the size of the unit, etc. Table 5 gives average emission factors for the gaseous pollutants in the three major categories of coal usage. As a rule of thumb, for these three categories, boiler capacities for power plants are generally above 100 x 10^6 Btu per hour, industrial boilers are in the range of 10 to 100 x 10^6 Btu per hour, and domestic and commercial boilers are generally below 10 x 10^6 Btu per hour capacity. It is generally advisable to deal with large coal burning plants (>100 x 10^6 Btu) on an individual basis.

The burning of coal also produces a particulate emission. The quantity of the emission is mostly dependent upon the ash content of the coal and the type of unit and control equipment used. One of the more interesting constituents of the particulate emission is benzo(a)-pyrene, which has been shown to be carcinogenic to laboratory animals. Table 6 provides average total particulate emission factors for various types of coal firing units without control equipment. Separate benzo(a)pyrene emission factors have been provided where available. The operation of electrostatic precipitators has no effect on the benzo(a)pyrene emission.

Table 7 gives the ranges of fly ash collection efficiencies for various types of control equipment when used on several types of furnaces. If the type of control equipment used is unknown, the uncontrolled emission factors can be refined to take into account the effect

Table 5. GASEOUS EMISSION FACTORS[a] (lb/ton of coal burned)

Pollutant	Power plants	Industrial	Domestic and commercial
Aldehydes (HCHO)	0.005	0.005	0.005
Carbon monoxide	0.5	3	50
Hydrocarbons (CH_4)	0.2	1	10
Oxides of nitrogen (NO_2)	20	20	8
Oxides of sulfur (SO_2)	38 S[b]	38 S[b]	38 S[b]

[a]Reference 14.

[b]S equals percent sulfur in coal.
Example: If the sulfur content is 2 percent, the oxides of sulfur emission would be 2 x 38, or 76 lb. of sulfur oxides/ton of coal burned.

Table 6. PARTICULATE EMISSION FACTORS (WITHOUT CONTROL EQUIPMENT)

Type of unit	Particulate emission,[a] lb/ton of coal burned	Benzo(a)pyrene emission,[b] µg/ton of coal burned
Pulverized - general	16A[c]	600
Dry bottom	17A[c]	
Wet bottom		
Without reinjection	13A[c]	
With reinjection	24A[c]	
Cyclone	2A[c]	6,000[d]
Spreader stoker		700
Without reinjection	13A[c]	
With reinjection	20A[c]	
All other stokers	5A[c]	100,000
Hand-fired equipment	20	12 x 10^6

[a]Reference 14.

[b]Reference 15.

[c]A equals percent ash in coal.
Example: If the percent ash in the coal is 10 percent, the ash emission for a cyclone unit would be 2 x 10 or 20 lb/ton of coal burned.

[d]Reference 16.

of control by using Table 8. Table 8 gives estimates of particulate emissions for "average" and "good" control. If the emission values without control from Table 6 are less than those from Table 8, the smaller number should be used. The values for average control were calculated from the present ASME Model Ordinance; those for good control are based upon a proposal being considered by the ASME Standards Committee for Emission of Smoke and Dust from the Combustion of Fuel for Indirect Heating. The proposal is still under study and has not been adopted as yet.[14]

B. Natural Gas

Table 9 shows the emission factors for the combustion of natural gas in power plants, industrial boilers, and domestic and commercial heating units. The calculations are based upon a density for natural gas of 0.05165 pound per standard cubic foot and a heating value of 1000 Btu per standard cubic foot.

C. Oil

The pollutants emitted in oil combustion are much the same as in coal combustion. Particulate emissions are considerably lower, however. As with coal, the sulfur oxide emissions vary with the sulfur content of the fuel. Table 10 gives the emission factors for large and for small sources.

CONCRETE BATCHING PLANTS

Concrete batching plants are generally simple arrangements of steel hoppers, elevators, and batching scales for proportioning rock,

Table 7. RANGES OF COLLECTION EFFICIENCIES FOR COMMON TYPES OF FLY ASH CONTROL EQUIPMENT[a]

Type of furnace	Range of collection efficiencies, %			
	Electrostatic precipitator	High efficiency cyclone	Low resistance cyclone	Settling chamber expanded chimney bases
Cyclone furnace	65 - 99[b]	30 - 40	20 - 30	-
Pulverized unit	80 - 99.9[b]	65 - 75	40 - 60	-
Spreader stoker	-	85 - 90	70 - 80	20 - 30
Other stokers	-	90 - 95	75 - 85	25 - 50

[a]Reference 14.

[b]High values attained with high efficiency cyclones in series with electrostatic precipitators.

Table 8. ESTIMATES OF CONTROLLED PARTICULATE EMISSIONS[a]

Type of control	Lb particulate/ton of coal burned		
	Power plants	Industrial plants	Domestic and commercial plants
Average	25	25	25
Good	10	15	20

[a]Reference 14.

Table 9. EMISSION FACTORS[a]

($lb/10^6$ ft^3 of natural gas burned)

Pollutants	Power plants	Industrial boilers	Domestic and commercial heating units
Aldehydes	1	2	negligible
Benzo(a)pyrene[b]	n.a.[c]	20,000 $\mu g/10^6$ ft^3	130,000 $\mu g/10^6$ ft^3
Carbon monoxide	negligible	0.4	0.4
Hydrocarbons	negligible	negligible	negligible
Oxides of nitrogen	390	214	116
Oxides of sulfur	0.4	0.4	0.4
Ammonia	n.a.[c]	0.3[d]	0.3[d]
Organic acids	n.a.[c]	62[d]	62[d]
Particulate	15	18	19

[a]Reference 17.

[b]Reference 15.

[c]Not available.

[d]Reference 9.

Table 10. EMISSION FACTORS[a]
(lb/1000 gal of oil burned)[b]

Pollutants	Large sources (1000 h.p. or more)	Small sources (1000 h.p. or less)
Aldehydes	0.6	2
Benzo(a)pyrene[c]	5000 μg/1000 gal	40,000 μg/1000 gal
Carbon monoxide	0.04	2
Hydrocarbons	3.2	2
Oxides of nitrogen (NO_2)	104	72
Sulfur dioxide	157 S[d]	157 S[d]
Sulfur trioxide	2.4 S[d]	2 S[d]
Particulate	8	12

[a]Reference 18.

[b]Density of fuel oil equals 8 lb /gallon and there are 42 gallons per barrel.

[c]Reference 15.

[d]S equals percent sulfur in oil.
Example: If the sulfur content is 2 percent, the sulfur dioxide emission would be 2 x 157, or 314 lb. SO_2/1000 gal. oil burned.

gravel, and sand aggregates with cement for delivery, usually in transit mixer trucks. Aggregates are usually crushed and sized in separate plants and are delivered by truck or belt conveyors to ground or other storage from which they can be reclaimed and placed in the batch plant bunkers.

By careful use of sprays, felt, or other filter material over breathers in the cement silos, and canvas curtains drawn around the cement dump trucks while dumping, dust losses can be controlled. Aggregate stocks in bunkers are wet down with sprays to prevent dusting. With careful operation, under stringent Los Angeles standards, losses in these plants can be held to about 0.025 pound of dust per yard of concrete. Uncontrolled plants have emissions of about 0.2 pound of dust per yard on concrete handled.[19]

FERROUS AND NON-FERROUS FOUNDRIES

The emission factors given in Table 11 are for various processes found in ferrous and non-ferrous foundries. The data are almost all from Los Angeles experience, but seem to be representative of the experience with these processes in other parts of the country. In gray iron cupolas, approximately 1725 pounds of casting are produced for each ton of raw material processed. In the electric steel melting furnace and the non-ferrous melting furnaces, it can be assumed that the weight of castings produced equals the weight of raw material processed.

Table 11. FERROUS AND NON-FERROUS FOUNDRY EMISSIONS[a]

Process	Aerosol emission factor, lb/ton of raw material processed	
	Uncontrolled	Controlled
Gray iron melting cupolas (avg.)	17.1	0.26[b]
Less than 48" I.D.	12.9	-
48-60" I.D.	19.5	-
Greater than 60" I.D.	18.9	-
Electric steel melting furnaces (avg.)	8.6	0.17[b]
Less than 5-ton capacity	10.6	-
5- to 20-ton capacity	5.7	-
50- to 75-ton capacity	9.6	-
Melting of red brass (< 7% zinc):		
Crucible or pot furnaces	3.3	-[c]
Rotary furnaces	21.3	10.1
Reverberatory furnaces	16.8	-
Electric furnaces	3	-
Melting of yellow brass (> 20% zinc):		
Crucible furnaces	14	5.1[c]
Rotary furnaces	-	22.8[c]
Reverberatory furnaces	-	5.7[b]
Electric induction type furnaces	0.7	-
Melting of bronze:		
Crucible furnaces	3.8	-
Rotary furnaces	30.6	4.7[b]
Melting of aluminum:		
Crucible furnaces	1.9	-
Reverberatory furnaces	5.2	2.1[d]

[a]Reference 17.

[b]With baghouse control.

[c]Slag cover used as the only control method.

[d]With packed column scrubber and either baghouse or electrostatic precipitator as secondary collector.

The control of emissions from gray iron cupolas varies depending upon the type of control equipment used. Typical collection efficiencies are: 75 to 80 percent for a high efficiency centrifugal collector; about 40 percent for a dynamic water scrubber; 96-99 percent for a fabric filter unit; and 94-98 percent for an electrostatic precipitator installation.

GASOLINE EVAPORATION

A study of the typical pattern of motor gasoline storage and handling reveals five major points of gasoline emission. These are:

1. Breathing and filling losses from storage tanks at refineries and bulk terminals.
2. Filling losses from loading tank conveyances at refineries and bulk terminals.
3. Filling losses from loading underground storage tanks at service stations.
4. Spillage and filling losses in filling automobile gas tanks at service stations.
5. Evaporative losses from the carburetor and gas tank of motor vehicles.

Breathing loss has been defined as that loss associated with the thermal expansion and contraction of the vapor space resulting from the daily temperature cycle. Filling loss has been defined as the vapors expelled from a tank (by displacement) as a result of filling.[20]

Splash and submerged fill have been defined by R. L. Chass, et al.,[21] as follows: "In splash fill the gasoline enters the top of the

fill pipe and then has a free fall to the liquid surface in the tank. The free falling tends to break up the liquid stream into droplets. As these droplets strike the liquid surface, they carry entrained air into the liquid, and a "boiling" action results as this air escapes up through the liquid surface. The net effect of these actions is the creation of additional vapors in the tank.

"In submerged filling, the gasoline flows to the bottom of the tank through the fill pipe and enters below the surface of the liquid. This method of filling creates very little disturbances in the liquid bath and, consequently, less vapor formation than splash filling."

Emission factors are given for both cone roof and floating roof storage tanks, as well as for splash and submerged fill in tank vehicles and service station tanks. The degree to which floating roof tanks and submerged fill are utilized varies from place to place. Ideally, the gasoline evaporative emission should be calculated on the basis of the percentage of local utilization of submerged fill and floating roof tanks. If this is not known, then 75 percent floating roof tanks and 50 percent submerged fill should be assumed. The effect of vapor recovery loading arms or tank compression systems, has not been considered.

An average emission factor for hydrocarbons from cone roof gasoline storage tanks is 47 pounds per day per 1000 barrels of storage capacity. For floating roof tanks storing gasoline, a typical hydrocarbon emission is 4.8 pounds per day per 1000 barrels of storage capacity. More precise

values for a specific locality can be calculated using methods in the American Petroleum Institute Bulletin 2517, entitled "Evaporation Loss from Floating Roof Tanks," and Bulletin 2518, entitled "Evaporation Loss from Fixed Roof Tanks." These are available from the American Petroleum Institute, Division of Technical Services, 1271 Avenue of the Americas, New York 20, New York.

Table 12 summarizes the emission factors for gasoline evaporation at the other four major points of emission.

IRON AND STEEL MILLS[25]

To make steel, iron ore (containing some 60 percent iron oxides) is reduced to pig iron, and some of its impurities are removed in a blast furnace; the pig iron is further purified in either open hearths, Bessemer converters, the basic oxygen process, or electric furnaces. Various alloying metals (chromium, manganese, etc.) are usually added to produce specialized types of steel.

Blast furnaces are charged with iron ore, coke, and limestone in alternating layers. To promote combustion, hot air is blown into the bottom of the furnace. To produce 1 ton of pig iron requires, on the average, 1.7 tons of iron ore, 0.9 ton of coke, 0.4 ton of limestone, 0.2 ton of cinder, scale, and scrap, and 4.0 to 4.5 tons of air.

Most of the coke used in the blast furnaces is produced in "by product" coke ovens from certain grades of bituminous coal. The distillation products produced are recovered for sale, and gases remaining

Table 12. GASOLINE EVAPORATION EMISSION

Point of emission	Lb/1000 gal of throughput	Percent loss by volume[a]
Filling tank vehicles[b]		
Splash fill	8.2	0.14
Submerged fill	4.9	0.08
50% splash fill and 50% submerged fill	6.4	0.11
Filling service station tanks[c]		
Splash fill	11.5	0.19
Submerged fill	7.3	0.12
50% splash fill and 50% submerged fill	9.4	0.15
Filling automobile tanks[d]	11.6	0.19
Automobile evaporation losses (gas tank and carburetor)[e]	92	1.50

[a]An average gasoline specific gravity of 0.73 is assumed.

[b]Reference 23.

[c]Reference 21.

[d] Reference 24.

[e]Reference 8.

after by-product recovery are used for heating the coke ovens and elsewhere in the plant. Smoke and gases escape only during charging and discharging operations; the rest of the process is normally air tight, but at some plants leakage of smoke and gases occurs because of poorly fitted oven doors.

Sintering plants convert iron ore fines and blast furnace flue dust into products more suitable for charging to the blast furnace. This is done by applying heat to a mixture of the iron-containing materials and coke or other fuels on a slow moving grate through which combustion air is drawn.

In the open hearth process for making steel, a mixture of scrap iron and steel and pig iron is melted in a shallow rectangular basin or "hearth" in which various liquid or gaseous fuels provide the heat. Impurities are removed in a slag. Oxygen injection (lancing) into the furnace speeds the refining processes, saves fuel, and increases steel production. Oxygen lancing increases the amount of fume and dust produced, however.

The basic oxygen process (the LD or Linz-Donawitz process) is new to the United States, but is gaining increasing application here. In this process, oxygen is blown onto the surface of the molten bath at high velocity, resulting in violent agitation and intimate mixing of oxygen with the pig iron.

Electric furnaces are used primarily to produce special alloy steels. Heat is furnished by direct-arc-type electrodes extending

through the roof of the furnace. In recent years oxygen has been used to increase the rate and uniformity of scrap meltdown and to decrease power consumption.

Bessemer converters are now seldom used. They are pear-shaped, tilting, steel vessels lined with refractory brick and clay. Impurities in the molten iron charge are oxidized by air blown through the metal for about 15 minutes.

A scarfing machine removes surface defects from the steel billets and slabs before they are shaped or rolled. This is done by applying jets of oxygen to the surface of the steel and thus removing a thin upper layer of the metal by rapid oxidation.[25] Emission factors for the various steel mill processes are shown in Table 13.

KRAFT PULP MILLS

Before the cellulose from wood can be made into pulp, the lignin that binds the cellulose fibers together must be removed. In the kraft process, this is done by treating with an aqueous solution of sodium sulfide and sodium hydroxide. This liquor is mixed with wood chips in a large, upright, pressure vessel, called a digester, and cooked for about 3 hours with steam. During the cooking period, the digester is relieved periodically to reduce the pressure build-up of gases.

When cooking is completed, the bottom of the digester is suddenly opened and its contents forced into the blow tank. Here, the major portion of the spent cooking liquor, containing the dissolved lignin,

Table 13. EMISSIONS FROM STEEL MILLS

(From reference 26, which is based on data in reference 25)

Operation	Before control		Emission with control				Approximate volume of gases handled
	Stack loading, grains/scf	Lb/ton of product	Control used[c]	Stack loading grains/scf	Lb/ton of product	Approximate efficiency, %	
Blast furnace	7-10	200	Preliminary cleaner (settling chamber or dry cyclone)[b]	3-6	-	60	87,000 scfm for a 1000-ton per day furnace.
			Primary cleaner (Wet scrubber)[b]	0.05-0.3-0.7[a]	5.4	90	
			Secondary cleaner (E.S.P. or V.S.)[b]	0.004-0.008	0.1-1.4	90	
Sintering machine	0.5-3.0	5-20-100	Dry cyclone	0.2-0.6	2.0	90	120,000-160,000 scfm for a 1000-ton per day machine.
			E.S.P. (in series with dry cyclone)	0.01-0.05	1.0	95	
Sinter machine discharge -crusher, screener and cooler	6.0	22	Dry cyclone	0.4	1.5	93	17,500 scfm for a 1000-ton per day machine.
Open hearth (Not oxygen lanced)	0.1-0.4-2.0	1.5-7.5-20.0	E.S.P.	0.01-0.05	0.15	98	35,000 scfm for a 175-ton furnace.
			V.S.	0.01-0.06	0.15-1.1	85-98	
			Baghouse	0.01	0.07	99	
Open hearth (With oxygen lance)	0.1-0.6-2.5	9.3	E.S.P.	0.01-0.05	0.2	98	35,000 scfm for a 175-ton furnace.
			V.S.	0.01-0.06	0.2-1.4	85-98	
Electric arc furnace	0.1-0.4-6.0	4.5-10.6-37.8	High efficiency scrubber	0.01	0.2	Up to 98	Highly variable depending on type of hood. May be about 30,000 scfm for a 50-ton furnace.
			E.S.P.	0.01-0.04	0.3-0.8	92-97	
			Baghouse	0.01	0.1-0.2	98-99	
Bessemer converter	0.8 - > 10	15-17-44	No practical method of control	-	-	-	-
Basic oxygen furnace	5-8	20-40-60	V.S.	0.03-0.12	0.4	99	Varies with amount of oxygen blown.
			E.S.P.	0.05	0.4	99	20 to 25 scfm per cfm of oxygen blown.
Scarfing machine	0.2 - 0.8	3 lb/ton of steel processed	Settling chamber	No data	No data	No data	85,000 scfm for a 45-inch, 4-side machine.
Coke ovens (By-product type)	No data	0.1% of coal processed (Rough estimate)	Emissions can be minimized through equipment design and operational techniques	No data	No data	No data	No data.

[a] When 3 values are given, such as 5-20-100, the center value is the approximate average and values at either end are the lowest and highest values reported. All data are highly variable depending on nature of a specific piece of equipment, materials being processed, and operating procedure.

[b] Used in series. Data on that basis.

[c] V.S. means venturi scrubber.
E.S.P. means electrostatic precipitator.

is drained, and pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter, where unreacted chunks of wood are removed. The pulp is then processed through intermittent stages of washing and bleaching, after which it is pressed and dried into the finished product.

Most of the chemicals from the spent cooking liquor are recovered for reuse in subsequent cooks. The spent, "black," liquor from the blow tank is concentrated first in a multiple effect evaporator and then in a direct contact evaporator utilizing recovery furnace flue gases.

The combustible, concentrated, black liquor thus produced is burned in a recovery furnace where the inorganic chemicals, to be recovered, fall to the floor of the furnace in a molten state.

The melt, consisting mainly of sodium sulfide and sodium carbonate, is withdrawn from the furnace and dissolved with water and weak causticizing plant liquor in a smelt tank. The "green" liquor thus produced is pumped into a causticizer where the sodium carbonate is converted to sodium hydroxide by the addition of calcium hydroxide. The calcium carbonate produced is converted into calcium oxide in a lime kiln, and is slaked to produce calcium hydroxide for further use in the causticizer. The effluent solution produced by the causticizing reaction is known as "white" liquor and is withdrawn and re-used in the digestion process.

Table 14 summarizes the emissions from the various processes involved in a kraft pulp mill.[27]

Table 14. EMISSION FACTORS FOR KRAFT PULP[a,b]
(lb/ton dry pulp produced)

Source	Gaseous pollutants			Particulate pollutants	Type of control
	Hydrogen sulfide	Methyl mercaptan	Dimethyl sulfide		
Digester blow system	0.1-0.7	0.9-5.3	0.9-3.8	negligible	Untreated
Smelt tank	n.a.[c]	n.a.[c]	n.a.[c]	20	Uncontrolled
				5	Water spray
				1-2	Mesh demister
Lime kiln	1	negligible	negligible	18.7	Scrubber (approximately 80% efficient)
Recovery furnace[d]	3.6	5	3	150	Primary stack gas scrubber
	3.6-7.0	n.a.[c]	n.a.[c]	7-16	Electrostatic precipitator
	0.7	n.a.[c]	n.a.[c]	12-25	Venturi scrubber
Multiple effect evaporator	1.2	0.04	n.a.[c]	negligible	Untreated
	0 - 0.5	0.003-0.030	negligible	negligible	Black liquor oxidation
Oxidation towers	n.a.[c]	n.a.[c]	0.1	negligible	Black liquor oxidation

[a]Reference 27.

[b]Reference 28.

[c]Not available.

[d]Gaseous sulfurous emissions are greatly dependent on the oxygen content of the flue gases and furnace operating conditions.

MINERAL ACID MANUFACTURE

A. Nitric Acid

In the United States, nitric acid is produced mainly by the high pressure catalytic reaction of vaporized, anhydrous ammonia and hot, filtered air. The resulting hot nitric oxide - air mixture is cooled and additional air is provided to complete the oxidation to nitrogen dioxide. The nitrogen dioxide gases are contacted with water in an absorbing tower to produce nitric acid. The major emissions are nitrogen oxide and nitrogen dioxide. Emissions of acid mist are normally insignificant.[29]

Emissions of nitrogen oxides range from 30 to 100 pounds per ton of acid produced, with 55 pounds of nitrogen oxides per ton of acid produced being a typical value.[30] Generally, 75 to 85 percent of the brown colored nitrogen dioxide will be reduced to colorless nitrogen oxide by a catalytic reduction unit. Because of extra fuel requirements, only about 25 percent of the total nitrogen oxides are reduced to nitrogen and oxygen by catalytic reduction.[31]

B. Phosphoric Acid

Phosphoric (orthophosphoric) acid is produced by two principal methods - the wet process and the electric furnace process. The wet process is usually employed when the acid is to be used for fertilizer production. Electric furnace acid is normally of higher purity and is used in the manufacture of high grade chemical and food products.

In the wet process, sulfuric acid and phosphate rock are reacted in agitated tanks to form phosphoric acid and gypsum. Phosphoric acid

is separated from the gypsum and other insolubles by vacuum filtration. Usually there is little market value for the gypsum. The phosphoric acid is normally concentrated to 50 to 55 percent P_2O_5 by evaporation. When superphosphoric acid is made, the acid is concentrated to between 70 and 85 percent P_2O_5. Emission of gaseous fluorides, consisting mostly of SiF_4 with some HF, will range between 20 to 60 pounds per ton of P_2O_5 produced.[32]

In the electric furnace process, phosphate rock, siliceous flux, and coke are heated in an electric furnace to produce elemental phosphorous. The gases containing the phosphorous vapors are passed through an electrical precipitator to remove entrained dust. In the "one-step" version of the process, the gases are next mixed with air to form P_2O_5 before passing to a water scrubber (packed tower) to form phosphoric acid. In the "two-step" version of the process, the phosphorous is condensed and pumped to a tower in which it is burned with air; and the P_2O_5 formed is hydrated by a water spray in the lower portion of the tower. The phosphoric acid mist formed is collected by scrubbing in packed towers.[33]

Emissions of P_2O_5 are in the range of 3.6 to 5.0 pounds of P_2O_5 per thousand pounds of elemental phosphorous (P_4) burned.[34]

C. Sulfuric Acid

In the United States, sulfuric acid is mainly produced by the contact process. Elemental sulfur or sulfur bearing materials are burned in clean air that has been dried by scrubbing with sulfuric acid. Among the sulfur bearing materials used are iron pyrites, acid sludges from refinery operations, and smelter off-gases. The sulfur dioxide produced is further oxidized to sulfur trioxide in the presence

of a platinum or vanadium pentoxide catalyst. The sulfur trioxide is then contacted with 98 to 99 percent sulfuric acid to produce a more concentrated acid. The principal emissions are sulfur dioxide and sulfuric acid mist.[35]

The emissions of sulfur dioxide range from about 20 to 70 pounds of sulfur dioxide per ton of acid produced and are unaffected by the presence of acid mist eliminators. Figure 1 illustrates the sulfur dioxide emissions for various conversion efficiencies for sulfur dioxide. Without acid mist eliminators, emissions of acid mist range from 0.3 to 7.5 pounds of acid mist per ton of acid produced. The use of acid mist eliminators reduces this emission to some 0.02 to 0.2 pound of acid mist per ton of acid produced.[36]

PETROLEUM REFINERIES

A modern refinery is a maze of pipelines, valves, pumps, towers, and vessels, but the entire operation can be conveniently discussed in terms of four major steps - separation, conversion, treating, and blending. The crude oil is first separated into selected fractions (e.g., gasoline, kerosine, fuel oil, etc.). The relative volume of each fraction is determined by the type of crude oil used. Since the relative volumes of each fraction produced by merely separating the crude may not conform to the relative demand for each fraction, some of the less valuable separation products are converted to products with a greater sale value by splitting, combining, or rearranging the original molecules.

In the catalytic cracking operation, large molecules are decomposed into lower-boiling fractions by heat and pressure in the presence

of catalysts. At the same time, some of the molecules combine to form larger molecules. The products of cracking are gaseous hydrocarbons, gasoline, kerosine, gas oil, fuel oil, and residual oil.

In catalytic reforming, gasoline is used as a feedstock and by molecular rearrangement, usually including hydrogen removal, gasoline of higher quality and octane number is produced. There are three types of reforming processes in use: fixed bed with and without catalyst regeneration, and the fluidized processes.

Polymerization and alkylation are processes used to produce gasoline from the gaseous hydrocarbons formed during cracking operations. Polymerization joins two or more olefins and alkylation unites an olefin and an iso-paraffin. Isomerization is another process used. In this process the arrangement of the atoms in a molecule is altered, usually to form branched-chain hydrocarbons.

The products from both the separation and conversion steps are treated, usually for the removal of sulfur compounds and gum-forming materials. As a final step, the refined base stocks are blended with each other and with various additives to meet product specifications and to arrive at the most valuable and salable combination of products.[34] Emission factors for petroleum refineries are shown in Table 15.

SOLVENT EVAPORATION FROM DRY CLEANING PLANTS

Almost all dry cleaning is performed with three solvents: tetrachloroethylene, Stoddard solvent, and safety 140° F solvent. Stoddard solvent has a minimum flash point of 100° F and a distillation range within 100° to 410° F. Recently a new petroleum solvent, called

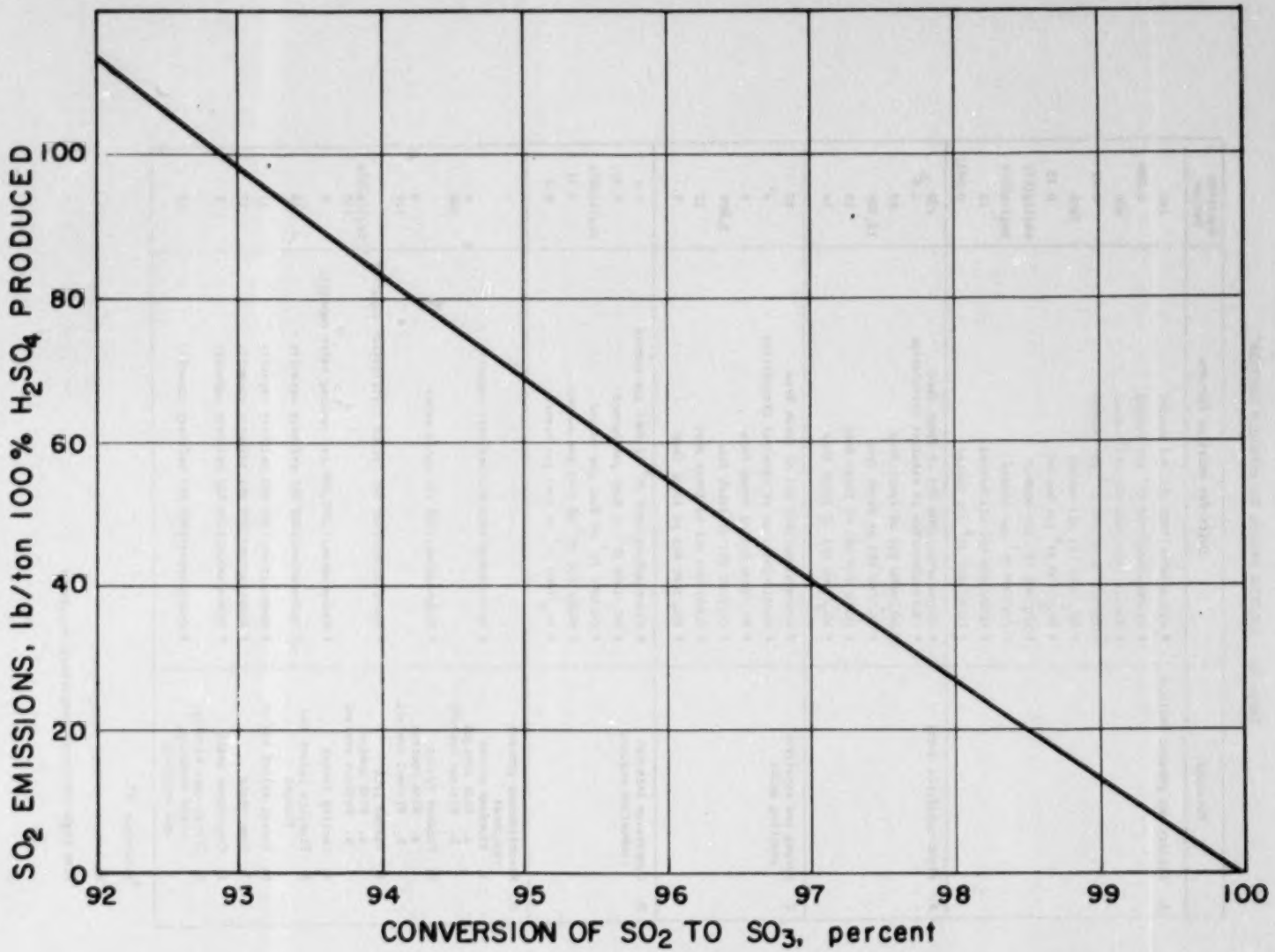

Figure 1. Sulfur dioxide emissions at various conversion efficiencies (per ton of equivalent 100% H_2SO_4 produced).[36]

Table 15. EMISSION FACTORS FOR PETROLEUM REFINERY[a]

Processes	Units for emission factors	Emission factor
A. Boilers and process heaters	# Hydrocarbon/1000 bbl oil burned	140
	# Hydrocarbon/1000 ft^3 gas burned	0.026
	# Particulate/1000 bbl oil burned	800
	# Particulate/1000 ft^3 gas burned	0.02
	# NO_2/1000 bbl oil burned	2900
	# NO_2/1000 ft^3 gas burned	0.23
	# CO/1000 bbl oil burned	negligible
	# CO/1000 ft^3 gas burned	negligible
	# HCHO/1000 bbl oil burned	25
	# HCHO/1000 ft^3 gas burned	0.0031
B. Fluid catalytic units	# Hydrocarbon/1000 bbl of fresh feed	220
	# Particulate/ton of catalyst circulation	1.8[b]
	# NO_2/1000 bbl of fresh feed	63
	# CO/1000 bbl of fresh feed	13,700
	# HCHO/1000 bbl of fresh feed	19
	# NH_3/1000 bbl of frosh feed	54
C. Moving bed catalytic cracking units	# Hydrocarbon/1000 bbl of fresh feed	87
	# Particulate/ton of catalyst circulation	4[c]
	# NO_2/1000 bbl of fresh feed	5
	# CO/1000 bbl of fresh feed	3,800
	# HCHO/1000 bbl of fresh feed	12
	# NH_3/1000 bbl of fresh feed	5
D. Compressor internal combustion engines	# Hydrocarbons/1000 ft^3 of fuel gas burned	1.2
	# NO_2/1000 ft^3 of fuel gas burned	0.86
	# CO/1000 ft^3 of fuel gas burned	negligible
	# HCHO/1000 ft^3 of fuel gas burned	0.11
	# NH_3/1000 ft^3 of fuel gas burned	0.2
E. Miscellaneous process equipment		
1. Blowdown system	# Hydrocarbon/1000 bbl refinery capacity	
a. With control		5
b. Without control		300
2. Process drains	# Hydrocarbon/1000 bbl waste water	
a. With control		8
b. Without control		210
3. Vacuum jets	# Hydrocarbon/1000 bbl vacuum distillation capacity	
a. With control		negligible
b. Without control		130
4. Cooling towers	# Hydrocarbon/1,000,000 gal cooling water capacity	6
5. Pipeline valves and flanges	# Hydrocarbon/1000 bbl refinery capacity	28
6. Vessel relief valves	# Hydrocarbon/1000 bbl refinery capacity	11
7. Pump seals	# Hydrocarbon/1000 bbl refinery capacity	17
8. Compressor seals	# Hydrocarbon/1000 bbl refinery capacity	5
9. Others (air blowing, blend changing, and sampling)	# Hydrocarbon/1000 bbl refinery capacity	10

[a]Reference 37.

[b]With electrostatic precipitator.

[c]With high efficiency centrifugal separator

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safety 140° F solvent, has been introduced that has a minimum flash point of 140° F, thus lessening the explosion hazard.

Chlorinated hydrocarbons are widely used as cleaning solvents. They are nonflammable and dissolve greases and oils more rapidly, including substances not soluble in petroleum solvents. Originally, carbon tetrachloride was used, but had to be discarded because of its toxicity and corrosiveness. Trichloroethylene is less toxic and not as corrosive as carbon tetrachloride. Tetrachloroethylene (perchloroethylene) is the most widely used chlorinated dry cleaning agent. It has a lower toxicity, is less corrosive than carbon tetrachloride, and does not bleed acetate dyes as trichloroethylene does. Because it is expensive, and a health hazard, tetrachloroethylene is often recovered by use of carbon adsorption beds.

Table 16 gives emission factors for chlorinated and non-chlorinated hydrocarbon dry cleaning solvents expressed in pounds per capita per day.[38]

REFUSE DISPOSAL AND OPEN BURNING

A. Incineration of Waste

Multiple chamber incinerators are made up of three refractory lined chambers in series. The first chamber, into which the combustible refuse is charged, is called the charging or ignition chamber. In the middle or mixing chamber, additional air is added to help consume any organic matter not completely burned in the ignition chamber. In the last chamber, called the combustion or expansion chamber, the combus-

Table 16. EMISSION FACTORS FOR DRY CLEANING PLANTS[a]

	LA data[b] January 1963	BAAPCD[c] data for 1963
Population	6,492,000	3,691,000
Tons chlor-hydrocarbons emitted/day	15	7.9
Tons petroleum solvents emitted/day	20	11.5
Total[d]	35	19.4
Tons of clothes cleaned/calendar day	158	92
Pounds of clothes cleaned/capita/year	18	18.3
Pounds of chlor-hydrocarbons emitted/capita/year	1.7	1.5
Pounds of hydrocarbon vapors emitted/capita/year	2.2	2.3
Pounds of total organic solvents emitted/capita/year	3.9	3.8

[a]Reference 38.

[b]Los Angeles County Air Pollution Control District data reported in reference 38.

[c]SanFrancisco Bay Area Air Pollution Control District.

[d]1958 data was extrapolated to 1963.

tion of gaseous organic materials is completed and the greater part of the flyash is settled out. This chamber is sometimes equipped with sprays and wetted baffles that reduce flyash emissions further, but have little effect on gaseous emissions.

Single chamber incinerators are generally simple contrivances, consisting of a firebox, door, grate, and flue. Emissions are generally high, but can be significantly reduced with auxiliary gas afterburners. Table 17 gives emission factors for the common types of municipal, industrial, commercial, apartment, and domestic incinerators.

B. Open Burning

Open burning, whether in dumps or in very simple backyard contrivances, gives rise to emissions that are extremely variable and difficult to measure. Dump fires generally smolder and burn less efficiently than backyard fires and thus have somewhat higher emissions. The data for backyard burning were derived from tests on burning a mixture of 50 percent newspapers and 50 percent grass clippings. Table 18 gives factors for burning dumps and for backyard burning.

C. Uncontrolled automobile body burning

The emission of particulates from the uncontrolled burning of automobile bodies would be about 10 pounds of particulates per automobile burned.[53]

Table 17. EMISSION FACTORS (lb/ton of refuse burned)

Pollutant	Municipal	Industrial and commercial[b]	
	multiple chamber[a]	Single chamber	Multiple chamber
Aldehydes	1.1	5-64	0.3
Benzo(a)pyrene[c]	6,000 µg/ton	100,000 µg /ton	500,000 µg /ton
Carbon monoxide	0.7[d]	20-200[c]	0.5
Hydrocarbons	1.4	20-50[c]	0.3
Oxides of nitrogen	2.1	1.6[c]	2.[h]
Oxides of sulfur	1.9	n.a.[g]	1.8[h]
Ammonia	0.3	n.a.[g]	n.a.[g]
Organic acids	0.6	n.a.[g]	n.a.[g]
Particulate	6[e];12[f]	20-25	4

Pollutant	Flue-fed apartment incinerator[i]	Domestic single chamber	
		Without auxiliary gas burning[k]	With auxiliary gas burning[i]
Aldehydes	5	6	2
Benzo(a)pyrene[c]	n.a.[g]	n.a.[g]	n.a.[g]
Carbon monoxide	n.a.[g]	300	n.a.[g]
Hydrocarbons	40[j]	100	1.5
Oxides of nitrogen	0.1	1.5	2
Oxides of sulfur	0.5	2.0	2
Ammonia	0.4	0.4	negligible
Organic acids	22	13	4
Particulate	26	39	6

[a] Reference 39.

[b] Reference 42.

[c] Reference 15.

[d] Reference 48.

[e] For incinerator with spray chamber. References 43-49,51.

[f] For incinerator without spray chamber. References 41,43,44,47-49,51,52.

[g] Not available.

[h] Reference 50.

[i] Reference 52.

[j] References 44,47,51.

[k] References 42,44,47,52.

Table 18. EMISSION FACTORS (lb/ton of refuse burned)

Pollutants	Burning dump[a,b]	Backyard burning[c]
Aldehydes	4	3.6
Benzo(a)pyrene[d]	250,000 µg/ton	350,000 µg/ton
Carbon monoxide	n.a.[e]	n.a.[e]
Hydrocarbons	280	280
Oxides of nitrogen	0.6	0.5
Oxides of sulfur	1.2	0.8
Ammonia	2.3	1.6
Organic acids	1.5	1.5[f]
Particulate	47	150[g]

[a]3 pounds per capita per day of refuse burned is assumed.

[b]Reference 47.

[c]Reference 41.

[d]Reference 15.

[e]Not available.

[f]References 40,41,47,52.

[g]Reference 52.

APPENDIX

SOURCES OF INFORMATION USEFUL IN CALCULATING TOTAL EMISSIONS

Combustion: Coal, Oil, and Natural Gas

A. Domestic

A method has been worked out for calculating domestic fuel use from data contained in the United States Census of Housing, 1960, Final Report HC (1) No. 15, State and Small Areas, U.S. Department of Commerce. There is a report for each state. In each state report, data are given on domestic fuel use for heating and cooking for Standard Metropolitan Statistical Areas and their constituent counties and independent cities within the state. A description of the above mentioned method is given in the section of this report entitled "A Method for Calculating Domestic Fuel Use from U.S. Bureau of Census Data."

B. Industrial and Commercial

In a report entitled "U.S. Bureau of the Census, Census of Manufactures: 1963, Fuels and Electric Energy Consumed in Manufacturing Industries: 1962, Series M63(1)-6," available from U.S. Government Printing Office, Washington, D.C., data are provided on purchased fuels and electrical energy used by industry for heat and power in standard metropolitan statistical areas with 40,000 or more manufacturing employees. Figures are provided for industrial use of coal, coke, fuel oil, gasoline, natural and manufactured gas, and other fuels for the various types of industries involved.

Total fuel usage in almost all publicly and privately owned steam-electric utility plants in the continental United States is provided in

"Steam-Electric Plant Factors" published annually by the National Coal Association, 1130 Seventeenth Street, N.W., Washington 6, D.C.

The Bureau of Mines of the United States Department of Interior annually publishes data on the distribution of bituminous coal and lignite in the various states and geographic area, tabulated according to producing districts of origin, method of transportation, and types of consumer use, in a report called "Bituminous Coal and Lignite Distribution and Markets, Mineral Industries Surveys." Other annual Bureau of Mines reports that may be helpful are Bulletin 446, "Typical Analysis of U.S. Coals," and RI 6461, "Analyses of Tipple and Delivered Sample of Coal Collected During the Fiscal Year" (annual). The "Keystone Buyers Guide", McGraw Hill Publishing Co., New York, 1963, contains a directory of fuel uses for all major utilities, cement plants, and coke ovens in the United States as well as analyses of sulfur and ash content of coals used in various areas.

Data on the sulfur and ash content of the fuel oils used in various regions of the United States are given in the U.S. Bureau of Mines publication, "Burner Fuel Oils, Mineral Industry Surveys" by O. C. Blade, published annually.

As a rule of thumb, it may be assumed that the commercial fuel usage is some two-thirds the domestic fuel usage.

In order to get more detailed information on the specific types of fuels and firing equipment used in an area, it is suggested that contact be made with local fuel suppliers and large users (such as electric utilities).

Refuse Disposal

In general, total refuse production is about 4 pounds per capita per day. About 75 percent of the refuse can be considered combustible. The portion of this amount disposed of by incineration varies greatly from place to place. The local health and sanitary authorities, as well as any private contractors, should be contacted to determine the amount of refuse disposed of by incinerators or by open burning in dumps.

Automotive and Diesel Emissions

Data on the number of automobiles, trucks, and diesel vehicles in use in a specific area can sometimes be estimated from data in "Motor Truck Facts" and "Automobile Facts and Figures" published by the Automobile Manufacturers Association, 320 New Center Building, Detroit 2, Michigan. The best source of this type of data is the State Motor Vehicle Bureau or a similar agency.

Figures on fuel consumption per vehicle can be calculated from data in Petroleum Facts and Figures, published annually by the American Petroleum Institute, 1271 Avenue of the Americas, New York 20, New York.

Exhaust emissions are sometimes expressed in the form of a graph of average speed versus pounds of emission per vehicle-mile. If the average speed and total vehicle miles driven in an area can be obtained from the local traffic or highway department officials, then the emissions can be obtained directly from these graphs. Examples of these graphs for carbon monoxide and hydrocarbons are attached (Figures 2 and 3). They were taken from Rose, A.H., et al, "Comparison of Auto Exhaust

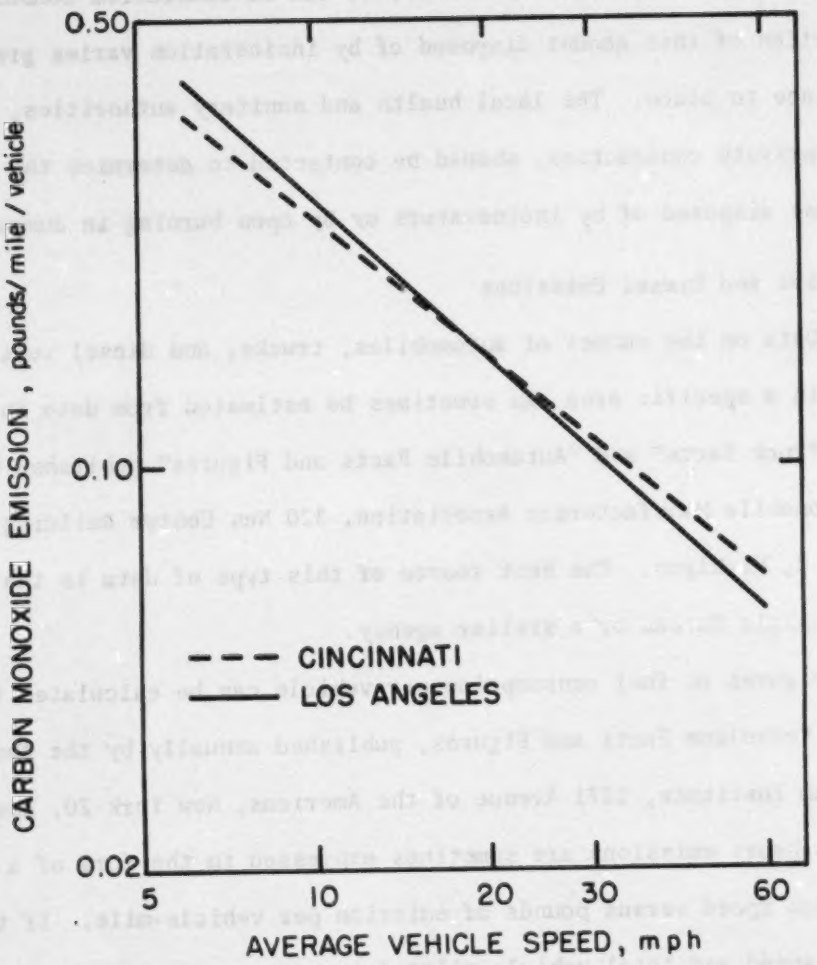

Figure 2. Pounds of carbon monoxide emitted per mile versus average vehicle speed.

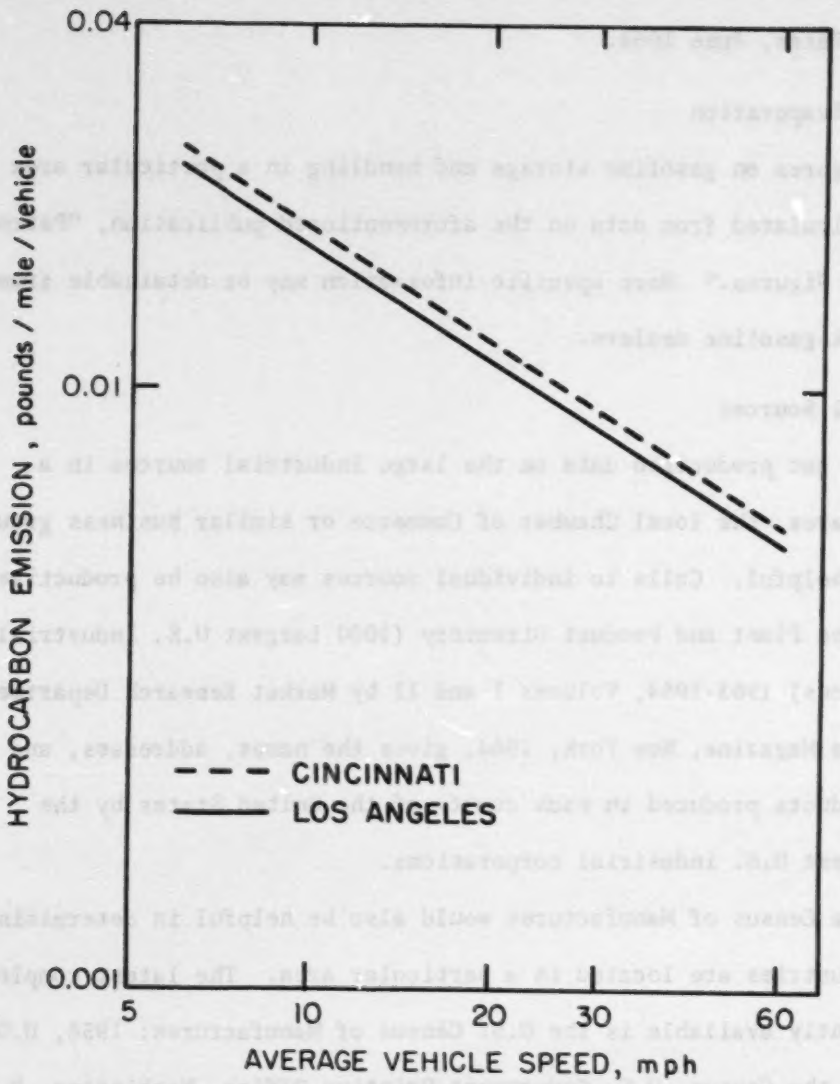

Figure 3. Pounds of hydrocarbons emitted per mile per vehicle versus average vehicle speed.

Emissions from Two Major Cities," presented at the APCA Annual Meeting, Houston, Texas, June 1964.

Gasoline Evaporation

Figures on gasoline storage and handling in a particular area can be calculated from data on the aforementioned publication, "Petroleum Facts and Figures." More specific information may be obtainable from local bulk-gasoline dealers.

Industrial Sources

To get production data on the large industrial sources in a specific area, the local Chamber of Commerce or similar business groups might be helpful. Calls to individual sources may also be productive. The Fortune Plant and Product Directory (1000 Largest U.S. Industrial Corporations) 1963-1964, Volumes I and II by Market Research Department of Fortune Magazine, New York, 1964, gives the names, addresses, and major products produced in each county of the United States by the 1000 largest U.S. industrial corporations.

The Census of Manufactures would also be helpful in determining which industries are located in a particular area. The latest complete set presently available is the U.S. Census of Manufactures: 1958, U.S. Bureau of the Census, U.S. Government Printing Office, Washington, D.C., 1961. The results of the 1963 Census of Manufactures should be published soon.

A METHOD FOR CALCULATING DOMESTIC FUEL USE FROM U.S. BUREAU OF CENSUS DATA[54]

A comprehensive census is made in the United States every 10 years. As part of this census, the characteristics and numbers of dwelling units in various political subdivisions are determined and reported in the Census of Housing. One item recorded in the census of Housing is the number of dwelling units heated with the various types of fuels. Converting this information into domestic fuel use for a given area is usually part of an overall inventory of air pollution emissions. A method of doing this is briefly outlined.

Basic assumptions and data are:

1. Average energy use for space heating in this country is 70×10^6 Btu/year - household.[55]
2. Average number of annual heating degree days for the country is 4600 (rounded).[55] A heating degree day is a unit representing one degree of declination from a given point (65° F) in the mean ambient air temperature for 1 day. It is a standard unit reported by the U.S. Weather Bureau. For example, if the average daily temperature is 50° F, the number of heating degrees for that day is:
   65° F - 50° F = 15.
3. Average size of household: 4.9 rooms/dwelling unit. Use 5 rooms/dwelling unit.[56]

4. Assumed fossil fuel characteristics

Fuel	Heating value	Overall efficiency of heating plant, %
Coal	26×10^6 Btu/ton	50
Oil	145,000 Btu/gallon	60
Gas	1,000 Btu/cubic foot	75

Derived data:

5. Heating requirements per household

$$\frac{70 \times 10^6 \text{ net Btu/year-household}}{4600 \text{ degree days/year}} = 15{,}200 \text{ net Btu/household-degree day}$$

6. Fuel requirements per household

(a) Coal

$$\frac{15{,}200 \text{ Btu/household-degree day}}{(.50)\ 26 \times 10^6 \text{ Btu/ton coal}} = 0.0012 \text{ ton coal/household-degree day}$$

(b) Oil

$$\frac{15{,}200 \text{ Btu/household-degree day}}{(.60)\ 145{,}000 \text{ Btu/gallon oil}} = 0.18 \text{ gallon/household-degree day}$$

(c) Gas

$$\frac{15{,}200 \text{ Btu/household-degree day}}{(.75)\ 1{,}000 \text{ Btu/cubic foot}} = 22.5 \text{ cubic feet/household-degree day}$$

7. Summary of estimating factors

Coal 0.0012 ton/household- ^{o}day

Oil 0.18 gallon/household- ^{o}day

Gas 22.5 cubic feet/household- ^{o}day

(based on 5 rooms/dwelling unit or household)

8. Sample calculation - Chicago, Illinois

(City of Chicago only)

Given data:

(a) From Census of Housing.[57] For purposes of this calculation method, the terms household and dwelling unit are used interchangeably.

Fuel	Number of dwelling units	(rounded)
Coal	458,974	460,000
Oil	332,634	335,000
Gas	346,125	350,000

(b) Average size of dwelling unit: 4.4 rooms/unit

(c) From local climatological data.[58,59]

Average number of annual heating degree days - 6,113

Calculated domestic coal use

(d) Annual domestic use of coal

$$460{,}000 \text{ dwelling units} \times \frac{0.0012 \text{ ton coal}}{\text{dwelling unit} - {}^{o}\text{day}} \times 6{,}113\ {}^{o}\text{day} =$$

3,380,000 tons coal/year

(e) Correction for number of rooms per dwelling unit in Chicago

$$3{,}380{,}000 \frac{\text{tons coal}}{\text{year}} \times \frac{4.4}{5.0} = 2{,}970{,}000 \text{ tons/year}$$

use 3,000,000 tons coal/year

In section 8, the annual domestic coal use was calculated. This calculation can be extended to the determination of fuel use by the day, month, or by heating season, by using the number of degree days for those periods. This information is available for most areas.[58,59]

The estimates herein derived are, of course, based on averages and only approximate the true fuel use. This method yielded comparable results when checked against estimates made by different methods.

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